APPLICATION FOR PATENT

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Title: Auto-focus method for a scanning microscope

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to an auto-focusing method and apparatus and, in particular, it concerns an auto-focusing method and apparatus for a scanning microscope.

By way of introduction, high-resolution scanners, such as scanning microscopes, are used to detect defects in wafers. The resolution of such scanners is typically better than 500 nanometers. Resolution is generally defined as the size of the smallest distinguishable feature. In order for the process to be effective the process needs to be accurate and fast. Prior art high–resolution scanners employ an auto-focus method as follows. First, the scanning head of the scanner moves to a new viewing region above the surface of the sample to be read. A measurement beam is passed through the optics of the scanner and is reflected off of the new viewing region back through the optics of the scanner. The focus of the scanner is then adjusted based upon analysis of the measurement beam. The scanner then reads from the new viewing region. Therefore, there is a time delay while adjusting the focus of the scanner.

With respect to an unrelated art, namely, low-resolution scanning systems, a method for reducing time delay associated with focusing

adjustments for low-resolution scanning systems is taught by U.S. Patent No. 6,325,289 to Mazzone. Mazzone teaches an apparatus and process for focusing a laser beam for reading optical codes. The apparatus includes an optical reader which enables optical codes to be read on objects carried on a supporting plane which is provided with a conveyor for moving the objects along a feeding direction. The optical reader includes a laser beam scanner, a data processing unit connected to the scanner, a first scanner for generating at least a first scan in a first scan plane, so as to measure the instantaneous distance of at least one point on the surface of each of the objects from the scanner, a second scanner for generating a plurality of second scans in a second scan plane, different from the first, so as to read the optical code on the object; and a data processing unit for adjusting the laser beam focal setting according to the distance measured with the first scan. The above apparatus employs a polygon mirror arrangement to perform the reading and measuring scans without moving the laser. Polygon mirror arrangements are not suitable for high-resolution scanning systems. Polygon mirror arrangements are typically employed for scanners having a maximum resolution of approximately half a millimeter. Therefore, the system taught by Mazzone cannot be applied to high-resolution scanning systems. Additionally, in accordance with one of the embodiments taught by Mazzone, the measurement and reading scans are not performed at the same time, thereby wasting time. In accordance with another embodiment taught by Mazzone, the measurement and reading scans are performed at the same time using separate parallel optical arrangements. Separate parallel optical arrangements may be

suitable for low-resolution requirements of reading optical codes, such as bar codes, but high-resolution applications generally require the measurement scans to be performed using the same optics with which the reading scan is performed.

There is therefore a need for a system and method for reducing delays associated with focusing adjustments.

SUMMARY OF THE INVENTION

The present invention is an auto-focus scanning microscope construction and method of operation thereof.

According to the teachings of the present invention there is provided, an auto-focus method for focusing an optical arrangement of a sub-micron optical system, the optical system including a head, at least part of the optical arrangement being included in the head, the optical arrangement being configured for reading from or writing to a surface of a medium, the head performing a scanning motion relative to the surface, the method comprising: (a) illuminating at least part of a first viewing region of the surface by the optical arrangement; performing a focus range measurement of a second viewing region of the surface, the step of configuring and the step of performing being performed substantially at the same time, wherein a centroid of the first viewing region is offset from a centroid of the second viewing region at least in a direction which is parallel to a direction of relative motion of the medium and the head; (b) providing relative movement between the

medium and the head in order for the optical arrangement to illuminate at least part of the second viewing region; and (c) adjusting the focus of the optical arrangement based upon the focus range measurement.

According to a further feature of the present invention, the step of performing is performed by sending a measurement ray through at least part of the optical arrangement.

According to a further feature of the present invention: (a) the optical arrangement includes a lens which is included in the head; and (b) the step of performing is performed by sending a measurement ray through the lens.

According to a further feature of the present invention, the measurement ray passes through an optical center of the lens.

According to a further feature of the present invention, the first viewing region and the second viewing region are non-overlapping.

According to the teachings of the present invention there is also provided a sub-micron optical system for reading from or writing to a surface of a medium, comprising: (a) an optical arrangement and a head, at least part of the optical arrangement being included in the head; (b) a drive mechanism configured for providing relative movement between the medium and the head in a drive direction; (c) an auto-focus measurement system; and (d) an auto-focus mechanical system configured to adjust the focus of the optical arrangement based upon at least one focus range measurement taken by the auto-focus measurement system, wherein: (i) the optical arrangement and the auto-focus measurement system are configured, such that, the optical

arrangement illuminates at least part of a first viewing region of the surface substantially at the same time that the auto-focus measurement system performs a focus range measurement of a second viewing region of the surface; and (ii) a centroid of the first viewing region is offset from a centroid of the second viewing region at least in the drive direction.

According to a further feature of the present invention, the auto-focus measurement system is configured to direct a measurement ray through at least part of the optical arrangement.

According to a further feature of the present invention: (a) the optical arrangement includes a lens which is included in the head; and (b) the auto-focus measurement system is configured to direct a measurement ray through the lens.

According to a further feature of the present invention, the auto-focus measurement system is configured to direct the measurement ray through an optical center of the lens.

According to a further feature of the present invention, the first viewing region and the second viewing region are non-overlapping.

According to the teachings of the present invention there is also provided an auto-focus method for focusing an optical arrangement of an optical system, the optical system including a head, the optical arrangement including a lens, the lens being included in the head, the optical arrangement being configured for reading from or writing to a surface of a medium, the head performing a scanning motion relative to the surface, the method

comprising: (a) illuminating at least part of a first viewing region of the surface by the optical arrangement; (b) performing a focus range measurement of a second viewing region of the surface, the performing including sending a measurement ray through the lens, the step of configuring and the step of performing being performed substantially at the same time, wherein a centroid of the first viewing region is offset from a centroid of the second viewing region at least in a direction which is parallel to a direction of relative motion of the medium and the head; (c) providing relative movement between the medium and the head in order for the optical arrangement to illuminate at least part of the second viewing region; and (d) adjusting the focus of the optical arrangement based upon the focus range measurement.

According to a further feature of the present invention, the measurement ray passes through an optical center of the lens.

According to a further feature of the present invention, the first viewing region and the second viewing region are non-overlapping.

According to the teachings of the present invention there is also provided an optical system for reading from or writing to a surface of a medium, comprising: (a) an optical arrangement and a head, the optical arrangement having a lens which is included in the head; (b) a drive mechanism configured for providing relative movement between the medium and the head in a drive direction; an auto-focus measurement system configured to direct a measurement ray through the lens; and (c) an auto-focus mechanical system configured to adjust the focus of the optical arrangement

based upon at least one focus range measurement taken by the auto-focus measurement system, wherein: (i) the optical arrangement and the auto-focus measurement system are configured, such that, the optical arrangement illuminates at least part of a first viewing region of the surface substantially at the same time that the auto-focus measurement system performs a focus range measurement of a second viewing region of the surface; and (ii) a centroid of the first viewing region is offset from a centroid of the second viewing region at least in the drive direction.

According to a further feature of the present invention, the auto-focus measurement system is configured to direct the measurement ray through an optical center of the lens.

According to a further feature of the present invention, the first viewing region and the second viewing region are non-overlapping.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

Fig. 1 is a schematic side view of a sub-micron optical system that is constructed and operable in accordance with a preferred embodiment of the invention;

Fig. 2 is an enlarged schematic side view of an auto-focus measurement system of the sub-micron optical system of Fig. 1;

Fig. 3 is a chart showing the operation of the sub-micron optical system of Fig. 1; and

Fig. 4 is a schematic plan view of a medium being scanned by the sub-micron optical system of Fig. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is an auto-focus scanning microscope construction and method of operation thereof.

The principles and operation of an auto-focus microscope according to the present invention may be better understood with reference to the drawings and the accompanying description.

Reference is now made to Fig. 1, which is a schematic side view of a sub-micron optical system **10** that is constructed and operable in accordance with a preferred embodiment of the invention. Medium **12** is typically a semiconductor wafer. Optical system **10** has an optical arrangement **16** and a head **18**. Optical arrangement **16** is configured for reading from, or writing to, a surface **14** of a medium **12**.Optical arrangement **16** generally includes a light source **36**, a light detector **38**, lenses and mirrors **40**. A part of optical arrangement **16**, which includes an objective lens **20**, is included in head **18**. Optical system **10** includes a drive mechanism **22**, which is configured to provide relative movement between medium **12** and head **18** in a drive direction **24**. Therefore, head **18** performs a scanning motion relative to surface **14**. It will be appreciated by those ordinarily skilled in the art that the

relative motion between head **18** and surface **14** is achieved either by moving head **18**, medium **12** or by moving both head **18** and medium **12**. Optical system **10** includes an auto-focus measurement system **26**. As optical system **10** is generally configured to allow head **18** to perform a bi-directional scanning motion, auto-focus measurement system **26** includes two auto-focus measurement detectors **28** and associated optical components which are described in more detail with respect to Fig. 2. One auto-focus measurement detector **28** operates when head **18** moves in one direction relative to surface **14**, and the other auto-focus measurement detector **28** operates when head **18** moves in the opposite direction relative to surface **14**. Each auto-focus measurement detectors **28** is configured to perform a focus range measurement by directing one or more measurement rays **30** through the optical center of objective lens **20** of optical arrangement **16**. The optical center of objective lens **20** is defined as a point in objective lens **20** where a ray passing through that point is not deflected significantly enough to effect focusing calculations based upon measurement rays **30**. Therefore, while optical arrangement **16** is reading from, or writing to, a first region below head **18**, one auto-focus measurement detector **28** performs a focus range measurement of a second region which is in front of the first region in the scan direction. Additionally, as measurement rays **30** pass through objective lens **20** of optical arrangement **16** the accuracy of the focus range measurement is improved. It should be noted that it is preferable to reduce the angle, *A*, which is between measurement rays **30** and a center line **34** of the light rays emitted by optical arrangement **16**

from head **18**, so that measurement rays **30** are less likely to be distorted by features on surface **14** of medium **12**, such as steps. The measurement of distance for focusing purposes is known in the art. Optical system **10** also includes an auto-focus mechanical system **32**. Auto-focus mechanical system **32** is configured to adjust the focus of optical arrangement **16** based upon one or more focus range measurements taken by auto-focus measurement system **26**. The auto-focus operation of optical system **10** is described in more detail with respect to Figs. 2 to 4.

Reference is now made to Figs. 2 to 4. Fig. 2 is an enlarged schematic side view of one auto-focus measurement detector **28**. Auto-focus measurement detector **28** typically has an associated lens **68** and piezoelectric focus adjuster **70** which adjusts the focus of lens **68**. Fig. 3 is a chart showing the operation of optical system **10** (Fig. 1). Fig. 4 is a schematic plan view of medium **12** being scanned by optical system **10**. The method of operation of optical system **10** is generally as follows. Optical arrangement **16** illuminates at least part of a viewing region **42** of surface **14**, with a plurality of light rays **72**, in order to read from, or write to, surface **14** (block **54**). Viewing region **42** is described as a "viewing" region in that optical arrangement **16** is only able to read from, or write to, those portions of surface **14** which can be viewed by optical arrangement **16**. For example, some surface features may be hidden from the view of optical arrangement **16** even though these features form part of surface **14**. Additionally, one auto-focus measurement detector **28** performs a focus range measurement of a viewing region **44** of surface **14** by sending

one or more measurement rays **30** through the optical center of objective lens **20** of optical arrangement **16** (block **56**). It should be noted that optical arrangement **16** reads from, or writes to, viewing region **42** at substantially the same time that auto-focus measurement detector **28** performs the focus range measurement of viewing region **44**. "Substantially the same time" is defined as both steps being performed simultaneously, overlapping or time multiplexing. It should be noted that generally, the time auto-focus measurement detector **28** performs the focus range measurement of viewing region **44**, optical arrangement **16** is positioned with respect to surface **14** to read from, or write to, viewing region **42**, even if optical arrangement **16** is not actually reading or writing at that time. Additionally, the centroid **46** of viewing region **42** is offset from the centroid **48** of viewing region **44** in a scan direction **50**, which is parallel to a direction of relative motion of medium **12** and head **18** (Fig. 1). Generally, to increase efficiency of the read/write process, optical system **10** is configured such that viewing region **42** and viewing region **44** are non-overlapping.

Drive mechanism **22** (Fig. 1) provides relative movement between medium **12** and head **18** in scan direction **50** in order for optical arrangement **16** to illuminate at least part of viewing region **44** for reading therefrom or writing thereto (block **58**). At the same time as the above movement step is performed, auto-focus mechanical system **32** (Fig. 1) performs a coarse adjustment of the focus of optical arrangement **16** based upon the focus range measurement performed by auto-focus measurement

detector **28** of viewing region **44** (block **60**). Therefore, optical arrangement **16** is coarsely adjusted before optical arrangement **16** is positioned with respect to surface **14** to read from, or write to, viewing region **44**.

Preferably, when optical arrangement **16** is positioned to read from, or write to, viewing region **44**, a fine focusing range measurement of viewing region **44** is performed via optical arrangement **16** using techniques known in the art. The fine focus range measurement is then used to perform a fine focusing adjustment of optical arrangement **16** (block **62**). As the majority of the focusing adjustment needed to accurately focus optical arrangement **16** with respect to viewing region **44** is performed, by the coarse adjustment, in advance of optical arrangement **16** being positioned to read from, or write to, viewing region **44**, time delays associated with prior art auto-focus systems are greatly reduced.

Once optical arrangement **16** is accurately focused onto viewing region **44**, optical arrangement **16** reads from, or writes to, viewing region **44** (block **64**). At substantially the same time that the above read/write step is performed, one auto-focus measurement detector **28** performs a focus range measurement of a viewing region **52** (block **66**). The centroid **74** of viewing region **52** is offset from centroid **48** of viewing region **44** in scan direction **50**. The above steps are repeated as necessary.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both

combinations and sub-combinations of the various features described hereinabove, as well as variations and modifications thereof that are not in the prior art which would occur to persons skilled in the art upon reading the foregoing description.